Technical and Physical Feasibility Fact Sheet
Alternative 38: Surface Modeling

Acknowledgements: This discussion, which follows the same basic format as the fact sheet it accompanies, provides additional details and information that support the conclusions presented in the fact sheet. It was written by Robert Leutheuser of Leutheuser Consulting as part of the "Evaluation of Alternative Actions for Technical, Physical, Hydrological, Environmental, Economic, Social, Cultural, and Legal Feasibility and Water Quality Issues and Legal Overview" contracted to Daniel B. Stephens & Associates, Inc.

1. Definition of Alternative

Increase monitoring and modeling of surface water system to improve water management at the watershed level, and retain excess water flow from entering Elephant Butte Reservoir during wet cycles.

> "Under the Rio Grande Compact, NM accrues credits for excess water flow and debits for deficits. A spillover (sic) of the Elephant Butte dam wipes out all accumulated debits. Proposal is to improve monitoring of the snow pack so that NM is able to predict how much water to let flow down to Elephant Butte and thereby manage the wet year water excess to NM's best interest."

2. Approach

- Review water management and predictive models that have been, are being developed, or scheduled to be developed, for use in the Upper Rio Grande basin (from the headwaters of the Rio Grande in southern Colorado to Elephant Butte Reservoir) that are pertinent to Middle Valley (Rio Grande Valley between Cochiti Dam and Elephant Butte Reservoir) water management. These could include hydrologic and climatological models. Cost estimates and time lines will be included where possible.

- Interview key water managers to determine what additional monitoring and modeling efforts would result in measurably improved water management. Cost estimates and time lines will be included where possible.

- Summarize historical records to identify and quantify Elephant Butte Reservoir spill events, and describe upstream reservoir conditions contemporary to the spills.

3. Alternative Analysis

Background. The improvement of hydrologic and predictive modeling and the supporting monitoring network can lead to more precise management of water stored in a system of reservoirs, which *could but not necessarily* result in water savings. The opportunities for improved water management are not limited to a single reservoir (i.e., Elephant Butte Reservoir), nor limited hydrologic cycles. Furthermore, it would be erroneous to couple improved monitoring and modeling to a reduction of releases of excess flows, or spills, from Elephant Butte Dam.

Models of hydrologic systems depend on computing capabilities, input data, knowledge of relationships between data, and understanding of the physical conveyance system as well as the institutionalized water operation “rules.” For river and reservoir management, the basic components of the hydrologic system are the water inflows (runoff, precipitation, groundwater discharge, transbasin imports), and the outflows (evaporation, evapotranspiration, groundwater recharge, diversions). These constitute the inputs to a reservoir-river routing model that attempts to predict the spatial and temporal effects of the inflows and outflows.

There is a broad interrelated network of organizations actively working on improvements to hydrologic modeling and monitoring that is, and will continue to, directly benefit water management in the Upper Rio Grande Basin. The complexity of the activities sometimes appears to rival the complexity of the physical system being modeled.

Within each major area of consideration, modeling is first addressed followed by a discussion of monitoring.

3.1 Technical Feasibility

Enabling New Technologies and Status

It is beyond the scope of this effort to comprehensively document all of the related modeling activities. It is the author's intent to address the major areas of research, development, and application; and describe some of the more salient efforts.

Collaboration. As a prelude to the discussion, it is important to note that there is a high degree of coordination and integration of efforts and products. This is accomplished through professional and institutional linkages: All federal agencies that are involved in water management have formed modeling and research groups; academic institutions have created centers dedicated to the task. A *sampling* of coordination groups of particular importance to the Middle Rio Grande water planning area is presented in Table 38A-1. Please note that other important coordination groups undoubtedly are active; their omission is not intentional.

Table 38A-1. Sampling of Hydrologic Modeling Coordination Groups

Group/Organization	Home Organization	Website
WaRSMPWatershed & River System Management Program	US Bureau of Reclamation	usbr.gov/rsg/warsmp
National Research Program	U.S. Geological Survey	water.usgs.gov/nrp
SAHRA Sustainability of semi-Arid Hydrology and Riparian Areas	University of Arizona	sahra.arizona.edu
Advanced Hydrologic Prediction Service	National Oceanic & Atmospheric Administration	nws.noaa.gov/oh.ahps
National Water & Climate Center	Natural Resources Conservation Service	wcc.nrcs.usda.gov
CADSWESCenter of Advanced Decision Support for Water and Environmental Systems	University of Colorado	cadswes.colorado.edu
Center for Nonlinear Studies	Department of EnergyLos Alamos National Lab	cnls.lanl.gov
Agricultural Research Services	U.S. Department of Agriculture	nos.ars.usda.gov

The Upper Rio Grande Water Operations Model is of particular importance to the Middle Rio Grande water planning area for the coordination and exploitation of advances made in the field of hydrologic and climatological modeling.

Modeling

Reservoir/River Routing Models. There is a wealth of hydrologic models available to assist water managers in various aspects of water management. In 1996, federal water management agencies determined, with the support from other agencies, the need to improve the modeling tools available for Upper Rio Grande Basin water management, to be called the *URGWOM (Upper Rio Grande Water Operations Model)*.[1] After a thorough review of alternatives, *RiverWare* was chosen as the appropriate model. RiverWare was cooperatively developed by the Bureau of Reclamation, Tennessee Valley Authority, and the University of Colorado's Center of Advanced Decision Support for Water and Environmental Systems (CADSWES). RiverWare is a generalized river basin modeling environment that can address the multitude of management objectives and institutional rules through an object-oriented approach (USBR, 2000).

As outlined in project literature (URGWOM, 2002), the purpose of URGWOM is to facilitate the more efficient and effective management of water in the upper basin. It will be used from the headwaters of the Rio Grande down to Elephant Butte Dam for integrated water operations, and extended to Fort Quitman, Texas for flood operations. It has four modules:

- Water Operations Model, to be used for determining reservoir releases;
- Accounting Model, to account for San Juan-Chama Project water;
- Planning Model, to be used for predictive functions, including supporting the Upper Rio Grande Water Operations Review; and,
- Forecast Model, to develop daily hydrographs throughout the basin.

URGWOM is designed to take advantage of, and is taking advantage of, all improvements in related measurement and modeling activities.

URGWOM's accounting model has been in use for a several years and the forecast model has been completed and is in use. Portions of the water management model are being used in conjunction with existing tools; work continues on its enhancement and testing, and it is scheduled to be fully operational in 2003. The planning model is also scheduled to be operational in 2003, its primary application to be for the Upper Rio Grande Water Operations Review (Yuska, 2002).

There are other contemporary hydrologic modeling activities ongoing in the basin as well, such as Los Alamos National Laboratory's Los Alamos Distributed Hydrologic System (LADHS), an integrated model under development for the Rio Grande Basin (R.Murray, 2001).

Climatological forecasting. Steady advancements are being made in weather forecasting, a critical component of water management. The National Weather Service, National Oceanic and Atmospheric Administration, National Center for Atmospheric Research and National Aeronautics and Space Agency, in cooperation with many others, are improving forecasts on all temporal and spatial scales. Research and development continue to look at the North Atlantic and Pacific oscillations on a global scale (Matthews, 2002), down to the local/subregional scale of how local land surface attributes affect local weather (the Land Data Assimilation System - LDAS) (NASA, 2002). Runoff modelers and water managers are incorporating the improvements as they develop.

Inflow modeling. Improving the predictions of river systems inflow is key element in improving hydrologic models, and an area of focused attention (Leavesly, 2002; Matthews, 2002; Yuska, 2002). Enhanced predictions rely on climatological forecasts as well as runoff forecasts.

In the Upper Rio Grande Basin, *snowmelt* accounts for the majority of the renewable water supply, averaging about 2.5 million acre-feet per year (Wilson, 1999), and for all practical and intent purposes, provides all the storable water for agricultural and other uses (USACE, 1989).

The NRCS and the National Weather Service cooperatively generate *snowmelt runoff forecasts*, based upon the snow measurement sites with information being correlated to historical conditions. Monthly "New Mexico Basin Outlook Reports" are issued January to June for the upper Rio Grande at 19 river stations. As the winter progresses, the forecasts become more accurate. Most water managers use the April 1 forecast as a basis for water management plans. From 1991 through the year 2000, the NRCS forecast of native runoff flows at the Otowi gage was within 10 percent of observed flows 40 percent of the time. They ranged from 47 percent (53,000 acre-feet) over observed flows in year 2000, to 26 percent (80,000 acre-feet) under observed flows in 1994. For Rio Chama inflow to El Vado Reservoir, forecasts for the same period were within 10 percent 5 out of 10 times for the same time period. The high forecast was 78 percent over observed (year 2000); the low, 45 percent under observed (year 1999).[2]

Remote sensing is increasing employed to monitor snow conditions. The National Aeronautics & Space Agency (NASA) initiated *MODIS* (Moderate Resolution Imaging Spectroradiometer) in 1999. MODIS uses satellite imagery to map snow cover at 500-meter or 1-kilometer grids (NASA 2002a), and in cooperation with other agencies such as the National Weather Service, has incorporated the capability to estimate snow-water equivalency in related activities (Matthews, 2002). Likewise the National Oceanic and Atmospheric Administration (NOAA) has initiated the Advanced Hydrologic Prediction Service to provide new forecasting products using a combination of remote sensing, data automation, and models to produce improved probability forecasts (NOAA, 2002)

The U.S. Department of Agriculture's Agricultural Research Services is developing the *Snowmelt Runoff Model*, which integrates many of the contemporary advances in runoff predictions into a user-friendly environment for water managers (USDA, 2002c).

The *Modular Modeling System* (MMS), developed by the USGS' National Research Program Precipitation-Runoff Modeling Project enables users to selectively couple the most appropriate relationships from applicable models to create a uniquely responsive model for specific applications (Leavesly, Date unknown). MMS is a physical attribute-based toolbox that incorporates such variables as elevation, slope, aspect, vegetation cover, and soil moisture for hydrologic response units to refine quantitative, spatial, and temporal runoff forecasts for snowmelt and precipitation events (Leavesly, 2002.; Matthews, 2002). MMS is currently being used in the Yakima, Truckee, and Gunnison river basins with encouraging results. For the Upper Rio Grande Basin, MMS-generated forecasts are being compared to URGWOM forecasts for 1998 and 1999, and the two systems are scheduled to be run concurrently for 2003 runoff (Yuska, 2002).

Outflow modeling. Outflows from a hydrologic system are also important to understand and quantify. Beyond the measured direct diversions from a river or reservoir, there are consumptive use, atmospheric and ground water outflows. Surface-groundwater relationships continue to be studied in the Middle Rio Grande Valley by a multitude of agencies. An area of applied technological advances is the measurement of consumptive use of riparian vegetation, crops, and evaporative losses from the river channel and wetted sands, coupled with mesoscale climatological data.

The Bureau of Reclamation, in partnership with many others, has been developing the *ET (evapotranspiration) Toolbox* over the past 4 years. The goal of the ET Toolbox is to develop a methodology for refining and automatically inputting riparian and crop evapotranspiration, open water evaporation, and rainfall estimates into URGWOM (Brower, et al., 2000). The Toolbox integrates NEXRAD (NEXt Generation RADar) rainfall estimates, weather station data, crop and riparian evapotranspiration requirements, GIS information, and land usage (Brower et al., 2000). Currently, it is based on a 4km X 4km grid cell system, with initial work focusing from Cochiti Dam to San Marcial. Middle Rio Grande Valley water managers now use the ET Toolbox information on a daily basis to assist them in making short-term water delivery decisions. When the ET Toolbox data is coupled with land use inventories and trend analyses, NASA's Land Data Assimilation System, etc., the ET Toolbox will also improve long-term water demand forecasting (Matthews, 2002). ET Toolbox data is being incorporated into URGWOM.

Measurement snow pack. To generate Upper Rio Grande Basin snowmelt runoff the forecasts, Natural Resources Conservation Service maintains a network of 24 high elevation snow monitoring sites, 12 each in Colorado and New Mexico. Nine of the sites in New Mexico are *SNOTEL* (SNOwpack TELemetry) sites, meaning they are fully automated and can transmit real-time data; four in Colorado are SNOTEL sites (USDA, 2002a). Basic SNOTEL sites have a pressure sensing pillow (for snow-water equivalency), storage precipitation gage, and an air temperature gage (USDA, 2002b). Snow depth sensors are being installed at SNOTEL sites (Murray, 2002) The conversion of the "manual course" sites to SNOTEL improves the accuracy of the forecasts, especially on the receding side of the snow pack (Murray, 2002). Existing sites are being converted to SNOTEL as sponsoring agencies fund the installation costs. For example, the New Mexico Interstate Stream Commission is currently funding the conversion of one site within the state per year (Murray, 2002).

River, inflow, and diversion measurements. Runoff can be measured after it enters a defined water course. The location of the stream gages is determined by established importance in estimating river system discharges and/or specific needs to monitor flows for accounting or research purposes. Although many measurements are collected by a variety of interests, it is the U.S. Geological Survey (USGS) that installs and maintains the system of *official stream gaging stations*. The gages generally measure and record the river stage (height of water at a set location), from which corresponding volumes are computed based on periodic field measurements.

Advances have been realized in the real-time communication of stream gage information. However, stream discharges remain computed values which are based upon periodic manual field measurements needed to continually recalibrate the stage-discharge relation curves. There is now the technology that uses *acoustic Doppler technologies* to measure discharges, resulting in more accurate and less time intensive field measurements (USGS, 1997). Commercial Doppler equipment is now on the market (SonTek/YSI, 2002) and the USGS/Albuquerque District anticipates that it will begin using technology for field measurements in the near future (Roark, 2002). Additionally, the USGS funds a program researching new technologies that may replace the current design of the stream gaging station, which has essentially remained unchanged for 100 years (Hirsch et al., 2001).

In the Upper Rio Grande Basin, including southern Colorado the USGS has 99 official stream gages, 51 of which transmit real-time data via satellite telemetry. Fourteen of the stations that do not have telemetry are in the Albuquerque metropolitan area’s storm drain system, and most of the other in high elevation small tributaries. In Colorado, the State of Colorado operates most of the gages; in New Mexico, the USGS operates the vast majority; a few being operated by either the Bureau of Reclamation or the USACE.[3] As with the NRCS’ SNOTEL sites, the USGS adds sites at the request and expense from other sponsoring interests.

Within the Middle Rio Grande water planning area, the rapidly improved and expanded water measurement system instituted by the Middle Rio Grande Conservancy District (MRGCD), with funding assistance from the New Mexico Interstate Stream Commission and U.S. Bureau of Reclamation, is of great importance. Since 1997 the MRGCD has installed 41 improved gages and flumes that accurately quantify diversions and return flows on key canals, laterals, drains, and wasteways . Eleven more are scheduled for construction in 2003. In addition, the MRGCD has installed nine weather stations throughout its service area. With few exceptions, the entire network is automated, transmitting real-time data to water managers (Gensler, 2002).

Municipal and industrial discharges into water courses are measured in compliance with water quality and/or water rights permit requirements. Groundwater withdrawals are likewise measured and recorded.

Infrastructure Development Requirements

Beyond the intensive analytic work required, improvements in modeling largely depend on improved data. This data can be obtained from satellite imagery, weather balloons, airplanes, ocean temperature stations, etc. In the more immediate sense, improved data for hydrologic modeling is obtained from water measurement, SNOTEL, and local weather stations. An increase in the number and sophistication of all of these is required for more real-time data and corresponding gains in the precision of the hydrologic models.

Total Time to Implement

Incremental improvements to both modeling and monitoring are continually being made and incorporated into water management tools. Therefore, no timetable can be established.

3.1.1 Physical and Hydrologic Impacts

There would be no physical or hydrologic impacts, for example, influences on water supply or demand, that would result from improved hydrologic monitoring and/or modeling. Any influences would be the result of water management decisions being made with improved tools.

The Middle Rio Grande Water Assembly has linked improved modeling within the watershed to "retain excess water from entering Elephant Butte Reservoir during wet cycles." For the purposes of this discussion, the documentation of spills from Elephant Butte Reservoir can serve as a *surrogate indicator* of water that the Middle Rio Grande planning area would like to retain for use within the region. As summarized in Table 38A-2, there have been seven years that Elephant Butte Reservoir has spilled since it began filling (this includes a 1996 "paper spill") in 1916, including four consecutive years in the 1980s (RGCC, various). The "actual spill of usable water," [4] as officially reported by Rio Grande Compact Commission, has ranged from 4,800 acre-feet (1996) to 510,000 acre-feet (1987).[5] Since the existing complex of upstream reservoirs has been in place, there have been seven spill events, discharging a total of 782,700 acre-feet of water in excess of downstream demands.

Table 38A-2: Elephant Butte Spills as Officially Reported by the Rio Grande Compact Commission

Year	1942	1985	1986	1987	1988	1995	1996
Quantity Spilled [a] (acre-feet)	470,100	7,800	47,600	510,400	187,600	24,500	4,800

[a] Values are for "actual spill of usable water." See footnote 4.

At the end of the years preceding the spills, Elephant Butte Reservoir ranged from being essentially full to 80 percent full. El Vado, the largest upstream reservoir permitted to store native Rio Grande water, ranged from about 45 to 70 percent of capacity in the Decembers prior to the spill years (available capacity to store about 100,000 acre-feet and 55,000 acre-feet, respectively.)

3.1.2 Environmental Impacts

There would be no direct environmental impacts associated with increasing modeling efforts in the Upper Rio Grande Basin. Water management decisions that rely on the expanded or improved models could, however, have insignificant-to-significant environmental impacts. Increasing and improving monitoring, such as the installation of new on-the-ground measurement stations would have insignificant localized effects on the environment.

3.2 Financial Feasibility

3.2.1 Initial Cost to Implement

Cost estimates for improving and expanding modeling efforts are unknown because of the seamless investments made in modeling efforts, as well as the plethora of cooperators and related activities that are combined for successful advances in modeling. Based upon the author's personal estimates, the multi-agency costs associated with the specific development of URGWOM may have been in the neighborhood of $1,000,000 per year since the team was assembled in 1997.

For measurement activities, the cost to convert NRCS manual course snow measurement sites to SNOTEL is estimated to be between $15,000 and $20,000 per site (Murray, 2002). It can cost between $10,000 and $35,000, depending on the need to construct a cable way, to install a USGS stream gaging station (Roark, 2002).

3.2.2 Potential Funding Source

All significant improvements to, and expansion of, hydrologic modeling in the Upper Rio Grande Basin are being made by agencies funded by public monies. All agencies and entities ultimately rely on taxpayers funding, with the exception of some public-private partnerships being developed by some agencies such as the Department of Energy.

3.2.3 Ongoing Cost for Operation and Maintenance

All models and monitoring sites require upkeep; the former to assimilate new data and make modifications for new computing capabilities and software; the later for physical operation and maintenance. The annual cost for the operation and maintenance of a USGS stream gage is estimated at $12,000/year (Roark, 2002). The NRCS absorbs the operation and maintenance costs for SNOTEL sites (Murray, 2002). The Middle Rio Grande Conservancy District employs one person full-time to operate and maintain its system of gages and weather stations with as-needed support from other staff. Once URGWOM is fully operational, it may cost about $250,000 a year to maintain and operate it.

4. Conclusions

4.1 Modeling

There are aggressive ongoing efforts to improve hydrologic and climatologic models. The key to the Upper Rio Grande Basin realizing the benefits from these activities is the Upper Rio Grande Water Operations Model, which is integrating the improvements as they occur. URGWOM and the national activities are well coordinated. It is principally federal public agencies that have taken the organizational and financial lead in the modeling activities, often with significant support from state and local public agencies. Advancements in modeling would be hastened by increasing earmarked funding for the sponsoring and contributing agencies. The public can assist securing additional funds through the appropriate legislative process, in coordination with the benefiting agencies.

4.2 Monitoring

As a whole, the monitoring system in place in the Upper Rio Grande Basin has improved over the past 5 years or so, and is adequate. There is, however, room for additional for improvements. The Natural Resources Conservation Service and the U.S. Geological Survey, responsible for the monitoring the snow pack and streams respectively, require partners to finance the upgrades of existing stations, or installation of new stations. The public can petition for financial support from federal, state, and local public agencies. The situation is similar for weather stations installed to support the ET Toolbox.

References/Bibliography

Brower, Albert L., C.L Hartzell, and S.P. Meyer. 2000. Evapotranspiration toolbox for the Upper Rio Grande Water Operations Model.. In *Proceedings, 2nd conference on environmental applications, 80th American Meteorological Society Annual Meeting, Long Beach California.* January 2000

Gensler, D. 2002. Personal communication between David Gensler (Middle Rio Grande Conservancy District) and Robert Leutheuser (Leutheuser Consulting). December 16, 2002.

Hirsch, R.M., J.M. Norris. 2001. National streamflow information program. US Geological Service Fact Sheet 005-01. February 2001.

Leavesly, G. Date unknown. *The Modular Modeling System (MMS) - a modeling framework for multidisciplinary research and operational applications.*

Leavesly, G. 2002. Personal communication between George Leavesly (U.S. Geological Survey, Water Resources Division, Central Region Research, Denver Colorado) and Robert Leutheuser (Leutheuser Consulting). November 13, 2002.

Matthews, D. 2002. Personal communication between David Matthews (U.S. Bureau of Reclamation, River Systems and Meteorology Group, Technical Service Center, Denver Colorado) and Robert Leutheuser (Leutheuser Consulting). November 12, 2002.

Murray, D. 2002. Personal communication between Daniel Murray (Natural Resources Conservation Service, Albuquerque New Mexico) and Robert Leutheuser (Leutheuser Consulting). December 10, 2002.

Murray, R. 2002. *Integrated modeling of the Rio Grande Basin*. Los Alamos National Laboratory, Center for Nonlinear Studies. July 2001. (Available at <http://www.cnls.lanl.gov>).

National Aeronautics & Space Agency, Land Data Assimilation Systems. 2002. *LDAS overview and description.* <http://ldas.gsfc.nasa.gov>. (Accessed January 2003).

National Aeronautics & Space Agency. 2002a. The MODIS Snow and Sea Ice Mapping Project, project description. <http://modis-snow-ice.gsfc.nasa.gov>. Last modified January 14, 2003.

National Center for Atmospheric Research. 2002. National Center for Atmospheric Research website. <http://www.ncar.ucar.edu>. (Accessed January 2003)

National Oceanic and Atmospheric Administration. 2002. Advanced hydrologic prediction service: water information for a stronger and safer America. <http://www.noaanews.noaa.gov>. Last updated January 21, 2003.

Pagano, T. 2002. Personal communication between Thomas Pagano (Natural Resources Conservation Service, Portland Oregon) and Robert Leutheuser (Leutheuser Consulting). November 25, 2002. (E-Mail November 26, 2002)

Rio Grande Compact Commissioners. 1942, 1985, 1986, 1987, 1988, 1995, and 1996. *Report of the Rio Grande Compact Commission to the Governors of Colorado, New Mexico, and Texas*.

Roark, M. 2002. Personal communication between Michael Roark (U.S. Geological Survey, Albuquerque District) and Robert Leutheuser (Leutheuser Consulting). December 12, 2002.

SAHRA. 2002. *Sustainability of semi-arid hydrology and riparian areas*. 2002. <http://www.sahra.arizona.edu>. Copyright 2001, Arizona Board of Regents (Accessed January 2003).

SonTek/YSI. 2002. Water velocity measurement instruments <http://www.sontek.com>. Last updated January 17, 2003.

U.S. Army Corps of Engineers (USACE). 1989. *Reevaluation of the Rio Grande Operating Plan*. U.S. Army Corps of Engineers, Albuquerque District. July 1989.

U.S Army Corps of Engineers (USACE). 2002. URGWOM. <http://www.spa.usace.army.mil/-urgwom>. Last updated December 24, 2002.

.U.S. Department of Agriculture Natural Resources Conservation Service, National Weather & Climate Center (USDA). 2002a. *National water and climate center—SNOW*. <http://www.wcc.nrcs.usda.gov/water/w_data.html>

U.S. Department of Agriculture Natural Resources Conservation Service, National Weather & Climate Center (USDA). 2002b. *SNOTEL data collection network fact sheet*. <http://www.wcc.nrcs.usda.gov/factpub/factpub.html. (Accessed January 2003)

U.S. Department of Agriculture Natural Resources Conservation Service, National Weather & Climate Center (USDA). 2002c. *Snowmelt runoff model development and testing*. <ftp://ftp.wcc.nrcs.usda.gov/ data/snow>. (Accessed January 2003)

U.S. Bureau of Reclamation. 2002. WaRSMP - Watershed and River System Management Program. <http://www.usbr.gov/rsmg/warsmp>. River Systems and Meteorology Group, Denver, CO. (Accessed January 2003)

U.S. Bureau of Reclamation Bureau of Reclamation. 2002. Watershed and river systems management programs. <http://www.usbr.gov/rsmg>. River Systems and Meteorology Group, Denver, CO. (Accessed January 2003)

U.S. Bureau of Reclamation. 2000. *RiverWare fact sheet*. River Systems and Meteorology Group, Denver, CO. April 2000.

U.S. Geologic Service, Water Resources Division (USGS). 2002a. NWIS web data for New Mexico. <http://nm.waterdata.usgs.gov>. (Accessed January 2003.)

U.S. Geologic Service (USGS). 1997. Streamflow information for the nation. USGS Fact Sheet FS-006-97.

U.S. Geologic Service (USGS). 1998. Water resources data, Colorado, water year 1997. USGS Water Data Report CO-97-1.

U.S. Geologic Service (USGS). 2002. Water resources data, New Mexico, water year 2002. USGS Water Data Report NM-01-1.

Wilson, L. 1999. Surface water hydrology of the Rio Grande Basin. In *WRRI conference proceedings, the Rio Grande Compact: its the law."* December 2-3, 1999. Santa Fe, New Mexico.

Yuska, Ma. 2002. Personal communication between Mark Yuska (U.S. Bureau of Reclamation, Upper Rio Grande Water Operations Model Team) and Rob Leutheuser (Leutheuser Consulting). November and December 2002.

Upper Rio Grande Water Operations Model, 2002. Website http://www.spa.usace.army.mil/urgwom

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[1] Signatories to the Memorandum of Understanding include: U.S. Army Corps of Engineers (USACE), Bureau of Reclamation, US Geologic Survey (USGS), Bureau of Indian Affairs, U.S. Fish & Wildlife Service, International Boundary and Water Commission, Cities of Albuquerque and Santa Fe, Los Alamos and Sandia National Laboratories, and Rio Grande Restoration. A broad range of professionals from many organizations and agencies are actively involved via the Technical Review Committee. URGWOM is permanently staffed by the USACE, Reclamation, and the USGS.

[2] Percent deviations derived from official NRCS data, provided by NRCS (Pagano, 2002).

[3] Data derived from information in USGS Water Resource Data reports (USGS 1998, 2002).

[4] Rio Grande Compact definition of **usable water**: "... all water, exclusive of credit water, which is in project storage and which is available for release in accordance with irrigation demands, including delivery to Mexico. Rio Grande Compact definition of **actual spill**: " ... all water which is actually spilled from Elephant Butte Reservoir, or is released there from for flood control, in excess of the current demand on project storage and which does not become usable water by storage in another reservoir; provided, that actual spill of usable water cannot occur until all credit water shall have been spilled."

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[5] In their 1989 report, the USACE stated that for the 3 spill years of 1986 through 1988, 1,185,000 acre-feet of water spilled from Elephant Butte. The source of their data is unknown.